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The main achievements of this proposal has been the introduction of a new family of global but sparse image features consisting of geometric arrangements of local responses. These features can serve as building blocks for template models, allowing for explicit modeling of the variability of the object family, and efficient computation of the template match. These features can also be accessed through decision trees to provide very accurate and efficient shape classifiers.

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DEFORMABLE TOPOLOGICAL TEMPLATES FOR IMAGE ANALYSIS

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FINAL PROGRESS REPORT

1 Publications

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Ph.D. December 1995.
Title: Deformable Templates and Image Compression.
Graduate student: Steve Wang.
Research topic: Automatic zipcode identification
Graduate student: Jiayu Li.
Research topic: Graphical templates for medical image analysis.

3 Summary

The initial goals of this proposal were the following:

1. Apply 2-dimensional elastic deformable template models to concrete image analysis problems such as tomography reconstruction, movement compensation and image compression.

2. Analyze these models on the theoretical level, including a rigorous formulation of the relevant topological issues.

3. Use these results to obtain a more systematic mechanism for generating templates, for determining the appropriate class of transformations and the appropriate priors.

4. Try to apply deformable template methods to problems in object recognition.

The application of the elastic deformation models to tomography was attempted in the context of tumor detection. Simple models for the tumor and the scalp were formulated together with a low dimensional family of allowable linear and non-linear perturbations. Instead of reconstructing the image using standard techniques and then searching for the tumor in the reconstruction, the deformation parameters of the model were obtained directly

from the count data, using the forward model of SPECT data generation. The actual optimization was carried out on a weighted least squares approximation to the Poisson model. This is described in progress report no. 1 (September, 1992) and in (Amit & Manbeck 1993).

Deformable template methods were applied to the compression of images of a given medical object. A template image was determined, and image matching techniques were used to warp the template into a data image. The warping is described with a small number of parameters. The residual image is very smooth and contains very little structure, and is compressed through tree structured vector quantization techniques, which are trained using several sample images. This method is described in progress reports no. 4 (February, 1995) and no. 5. (February, 1996) and in (Ambrosius 1995).

The analysis of the topological aspects of the 2-d elastic deformation models is descried in progress report no. 2 (January, 1993) and in (Amit 1992*b*). This analysis led to the development of graphical template models which solve many of the issues raised in item 3 above. The graphical models are descriptions of geometric arrangements of landmarks. The landmarks are defined through simple local operators, various linear or non-linear filters. The models are invariant to a large range of scales, translations and certain deformations. The constraints imposed by the geometric arrangement ensure that the chance of a random occurrence is very low, and typically a good arrangement will be found only at the correct locations on the object which is being modeled. The invariances ensure robustness to the natural variability in shapes of given anatomies. These models are described in progress reports no. 3 (March, 1994), and no. 4 (February, 1995), as well as in (Amit 1994),(Amit & Kong 1996) and (Amit 1995). In the latter publication an extensive test of the algorithm on 204 axial MRI brain images from 68 patients is reported.

Graphical templates allow for explicit modeling of the templates, and for more appropriate definition of the relevant transformations. They are very efficient computationally, and avoid the issues of local minima encountered in the relaxation methods used to solve the elastic models, moreover no initialization is required. Indeed the graphical template methods can serve as initialization to elastic deformation models. This was heavily used in the compression algorithms described in (Ambrosius 1995).

Initially it was proposed to use templates for object recognition. Various drawbacks of this approach were soon encountered. Most important is the computational issue of trying all templates on a given object. This becomes a serious concern in problems with hundreds of object types. The modeling issue, generating templates for each object is also a considerable problem. However it was noted that the basic ingredients of the graphical template models, e.g. geometric arrangements of landmarks representing local topographic codes,

could serve as of universal features for object recognition. Since geometric arrangements of local responses can be described through labeled graphs there is a natural partial ordering of these arrangements, involving more and more complex arrangements. Decision trees are particularly suitable for accessing this partially ordered set of features. They can be used simultaneously to identify the informative features for a certain classification problem and as classifiers. Multiple and randomized trees are used to overcome estimation problems associated with small data sets and achieve a high degree of robustness of the classifier.

The application of these ideas to shape recognition is described in progress reports no. 4 and no. 5 and in (Amit & Geman 1994), (Amit et al. 1995), (Geman et al. 1996), and (Amit & Geman 1996). Experiments with hundreds of shape classes corresponding to perturbed versions of 293 LaTeX symbols show the scalability of this method to very large dimensional problems. Furthermore possible connection with functions of the visual cortex have been explored.

The main achievement of the research over the past four years has been the use of sparse image features in the form of global geometric arrangements of local responses, both for registration and for recognition. The algorithms are very efficient and accurate. In recognition problems, state of the art classification rates were achieved on the NIST handwritten digit database.

The current aim of research is to achieve full integration of the registration and the recognition methods. This needs to be done at several levels.

1. Modeling: use decision tree techniques to derive the graph models automatically from learning data, instead of one model, many can be derived thus providing more robust registrations.

2. Focusing: use the registration methods to identify important sub-regions in the image, which can be further analyzed using classification trees. This should yield new and efficient object finding algorithms, for example face finding algorithms.

3. Final testing through registration: template registration can be used for disambiguation between a small number of candidate classes chosen by the classification algorithm.